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WATERTOWN ARSENAL LABORATORIES

ASSESSMENT OF 9310 STEEL FOR CARBURIZED COMPONENTS IN M14 RIFLES

TECHNICAL REPORT WAL TR 739.1/4

BY

PAUL V. RIFFIN

AND

JOSEPH L. SLINEY

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M14 RIFLE

WATERTOWN ARSENAL
WATERTOWN 72, MASS.

AD

Small arms, rifle M14

Materials evaluation

Carburized steel,
9310 and 8620

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ABSTRACT

In a recent study on the evaluation of SAE 8620 steel used in carburized components of M14 rifles, it was suggested that an investigation be conducted on the heat treatment, characteristics, and toughness of a lower carbon, higher alloy steel.

In the current investigation, the hardenability, microstructure and V-notch Charpy impact properties of SAE 9310 steel were evaluated. The results have been compared with those of 8620 steel, and recommendations are made regarding the use of the 9310 steel for carburized components for critical service applications.

Paul V. Riffin
PAUL V. RIFFIN
Supervisory Physical Metallurgist

Joseph L. Sliney
JOSEPH L. SLINEY
Mechanical Engineer

APPROVED:

J. F. Sullivan
J. F. SULLIVAN
Director
Watertown Arsenal Laboratories

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INTRODUCTION

A recent study* was conducted to determine the applicability of carburized SAE 8620H steel in M14 rifle bolts and receivers. The study revealed that such a material possessed a borderline hardenability for the section size involved, and its heat treatment required very close control in order for the material to meet the minimum toughness and fatigue properties required for carburized components. Watertown Arsenal recommended that an alternate steel of lower carbon content and higher hardenability be considered. Consequently, it was decided to investigate SAE 9310 steel which is employed for carburized components used in other severe service applications. It was expected that the 9310 steel would aid in providing improved toughness and in permitting a wide latitude in heat treatment.

TEST PROCEDURE

Jominy end quench hardenability tests were conducted on samples of both 8620H and 9310 steels. Carburized V-notch Charpy impact specimens were machined to final dimensions before the carburizing heat treatment, which was accomplished at Springfield Armory using liquid salt carburizing. Similar specimens (not carburized) were heat treated at Watertown Arsenal using neutral salt in place of carburizing salt. Uncarburized specimens were rough machined before heat treatment and finish machined and notched after heat treatment. The effect of tempering temperature was investigated by impact testing conducted at -40 F. In addition, temperature transition curves and the effect of precracking on impact properties were ascertained for selected heat treatments. Since bar stock was employed, the impact tests were conducted in the longitudinal direction only. (The microstructures resulting from various heat treatments were determined on broken impact bars.)

DATA AND DISCUSSION

Chemical Composition

The SAE 9310 steel and the resulfurized SAE 8620H steel, with which it is compared, were obtained in the form of bar stock from Springfield Armory. The chemical analyses obtained at this Arsenal on the two materials are presented in Table I.

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*SLINEY, JOSEPH L., Mechanical and Metallurgical Properties of Carburized 8620H Steel for M14 Rifle Components, Watertown Arsenal Laboratories, WAL TR 739.1/3, November 1961.

TABLE I

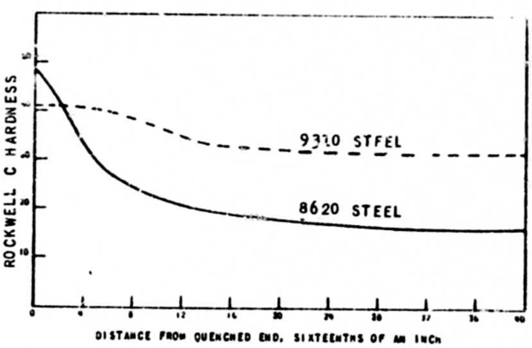
CHEMICAL ANALYSES

	C	Mn	Si	Ni	Cr	Mo	P	S
SAE 9310	0.11	0.60	0.32	3.21	1.24	0.11	0.010	0.009
SAE 8620	0.20	0.83	0.31	0.50	0.52	0.22	0.014	0.045

Several differences in these two alloy steels are of particular importance. The low carbon content of 9310 limits the maximum as-quenched hardness to about 42 Rockwell C as compared to 48 Rockwell C for the 8620 steel. However, the higher alloy content (particularly the nickel) also results in a high percentage of retained austenite in the carburized case. The sulfur content of the 8620 steel is relatively high because of resulfurization. The advantage of small additions of sulfur can only be determined by conducting machinability tests, preferably by machining of parts. Although resulfurized 8620 steel is generally considered to have better machinability than 9310 steel, the relative difference must be assessed on the basis of all the machining required on the complex components involved. Based on limited experience in machining specimens for this study it is expected that the 9310 steel will, in fact, be superior to the 8620 steel.

Hardenability Tests

The Jominy end quench hardenability tests were conducted according to the standard ASTM procedure on both 9310 and 8620 steel, and the results are plotted in Figure 1. The samples of bar stock examined fell within the ASTM H-bands for the respective steel types. The marked differences in these two steels are apparent from the curves of Figure 1. The maximum as-quenched hardness of 8620 at the water-quenched end of the test bar is over 45 Rockwell C. As the distance from this end increases and the cooling rate correspondingly decreases, there is a sharp drop in hardness. Since the cooling rates in the M14 rifle bolts and receivers are equivalent to distances of from 2/16 to 6/16 inch on the end quench bar, marked differences in the core hardness can be expected in production parts made from low hardenability steels. The maximum as-quenched hardness of the 9310 steel is 41 Rockwell C, and the hardenability curve is almost flat to at least 6/16 inch. As a result, when this steel is employed, the maximum core hardness of the lugs or other thin sections cannot exceed 41 Rockwell C; yet the heavier section will be quenched to a tough, martensitic microstructure at essentially the same hardness level.



SAE	C	Mn	Si	Ni	Cr	Mo	Austenizing Temp. F
9310	0.11	0.60	0.32	3.21	1.24	0.11	1600
8620	0.20	0.83	0.31	0.50	0.52	0.22	1575

Figure 1. END QUENCH HARDENABILITY CURVES OF SAE 9310 AND 8620 STEELS

Metallographic Examination

A metallographic investigation was conducted on selected Charpy impact specimens from both materials to determine the depth of carburization and microstructure of the case and core. Typical microstructures resulting from the heat treatments employed on the two materials are presented in Table II. Because of the low hardenability and high carbon

TABLE II

METALLOGRAPHIC RESULTS

Steel	Heat Treatment	Rockwell C Hardness		Case Depth (inch)	Microconstituents(%)	
		Case	Core		Case	Core
9310	A. Carburize 1-2/3 hr at 1600 F; quench in agitated oil (150 F); temper 1 hr at 400 F	56.0	39.5	0.014	75A 25M	100M
8620	B. Carburize 1-2/3 hr at 1575 F; quench in agitated oil (150 F); temper 1 hr at 375 F	57.0	40.5	0.015	5A 95M	5F 80HB 15M
8620	C. Carburize 1-2/3 hr at 1575 F; quench in warm water; temper 1 hr at 375 F	59.5	47.0	0.013	5A 95M	100M

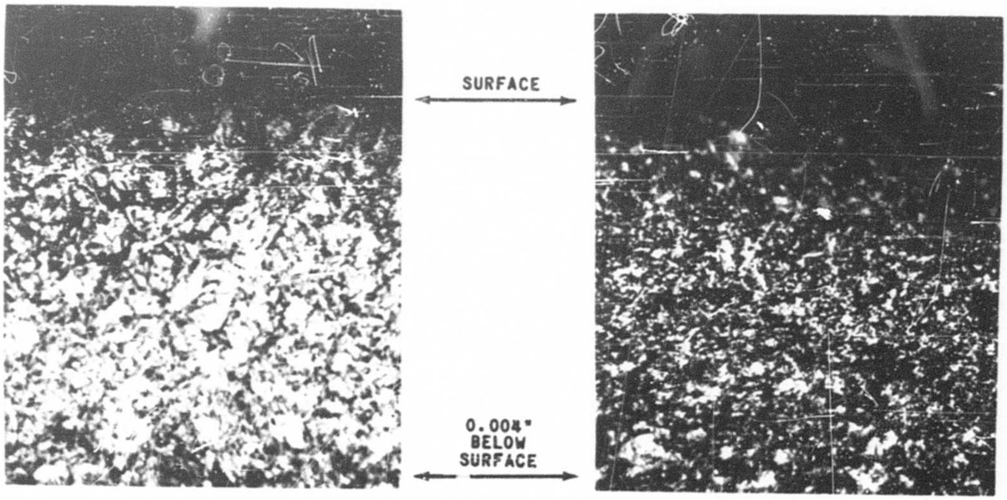
NOTE: F - Free Ferrite; HB - High Temperature Bainite; M - Tempered Martensite; A - Austenite (Retained)

content of the 8620 steel, it was not possible to heat treat specimens to both the desired core hardness (40 Rockwell C) and microstructure (100% tempered martensite) simultaneously when using the required draw temperature (375 to 400 F). Comparisons were made with specimens of 8620 steel heat treated to 100 percent martensite with a core hardness of 47 Rockwell C and others heat treated with a core hardness of 40 Rockwell C having a high percentage of nonmartensitic constituents. The 9310 steel was readily heat treated to the desired hardness of 40 Rockwell C and 100 percent tempered martensite using a low temperature draw.

The high nickel content of the 9310 steel results in the high percentage of retained austenite at the outer surface of the carburized case. Although equally high percentages of retained austenite have occasionally been observed in the 8620 steel, it is normally quite low (below 10%). The retained austenite lowers the hardness for a depth of about 0.005 inch from the surface; therefore, the fatigue and wear properties may be adversely affected. Most of this retained austenite, however, can be transformed to martensite by a "deep freeze" treatment,

see Figure 2. The effect of this treatment on the surface hardness of the impact specimens as measured by superficial Rockwell tests using the 15N scale is as follows:

Treatment	15N Readings	Converted to Rockwell C
a. None	85.0, 85.3, 86.3, 85.3	49 to 51
b. Cooled 2 hr at -110 F	91.8, 91.3, 92.0, 91.3	62 to 65



a
75% RETAINED AUSTENITE

b
LESS THAN 10% RETAINED AUSTENITE

Figure 2. RETAINED AUSTENITE IN CARBURIZED SURFACE OF 9310 STEEL

The subzero treatment increased the surface hardness of the 9310 steel to an acceptable level for good fatigue and wear resistance. Although no fatigue tests were conducted, 9310 steel would be expected to exhibit endurance limits equal to those reported previously for the 8620 steel, and superior fatigue properties at high stress levels (finite life portion of fatigue curve) because of superior core toughness.

Impact Properties

The results of V-notch Charpy impact tests at -40 F on 9310 steel at various tempering temperatures are presented in Table III. The energy absorbed, fracture appearance and hardness of case and core are listed. Results of similar tests obtained on 8620 steel are presented in Table IV. The results are also plotted in Figures 3 and 4 to show a comparison of the two steels in the uncarburized and carburized conditions respectively. It can be observed that the carburizing treatment which produces a hard nondeforming surface resulted in a marked decrease in the energy absorbed

TABLE III

TEMPERING CHARACTERISTICS OF 9310 STEEL

Tempering Temperature[1] (deg F)	Uncarburized			Carburized			
	Energy Absorbed[2] (ft-lb)	Fracture Fibrosity (%)	Rockwell C Hardness	Energy Absorbed[2] (ft-lb)	Fracture Fibrosity (%)	Rockwell C Hardness	
						Core	Case
As quenched	44.4	100	38.5	22.2	100	39.8	60.8
200	44.4	100	38.6	20.1	100	38.5	60.9
300	46.1	100	38.8	21.5	100	40.0	59.0
400	50.9	100	39.0	21.1	100	39.6	55.7
500	47.4	100	38.8	25.1	35	38.3	53.8
600	47.8	85	38.6	9.2	10	39.5	52.5
700	36.5	55	37.3	7.5	0	38.3	49.8
800	45.7	75	36.0	6.4	0	33.8	47.5
900	58.7	85	34.1	21.5	5	33.4	44.6

NOTE: [1]All specimens quenched from 1600 F into agitated oil.

[2]All specimens tested at -40 F.

TABLE IV

TEMPERING CHARACTERISTICS OF 8620H STEEL

Tempering Temperature[1] (deg F)	Uncarburized			Carburized			
	Energy Absorbed[2] (ft-lb)	Fracture Fibrosity (%)	Rockwell C Hardness	Energy Absorbed[2] (ft-lb)	Fracture Fibrosity (%)	Rockwell C Hardness	
						Core	Case
As quenched	17.5	20	47.0	2.5	0	46.6	64.8
200	15.8	15	47.4	2.5	0	45.6	64.4
300	18.1	25	47.0	3.4	0	45.6	61.7
400	18.8	35	45.9	3.4	0	45.9	58.6
500	15.5	20	43.7	1.8	0	42.6	55.6
600	9.5	10	42.0	1.8	0	41.0	53.4
700	15.8	15	40.7	2.3	0	41.8	50.6
800	31.4	75	38.2	9.7	0	38.8	46.7
900	47.8	100	33.8	30.2	100	34.6	43.9

NOTE: [1]All specimens quenched from 1580 F into warm water.

[2]All specimens tested at -40 F.

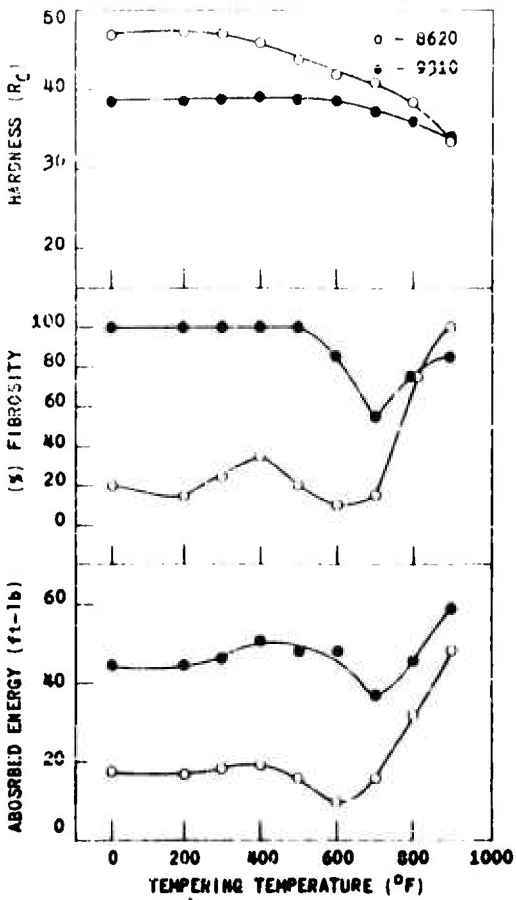


Figure 3. EFFECT OF TEMPERING TEMPERATURE ON HARDNESS AND V-NOTCH CHARPY IMPACT PROPERTIES AT -40 F - HEAT TREATED (UNCARBURIZED) SAE 9310 AND 8620 STEELS

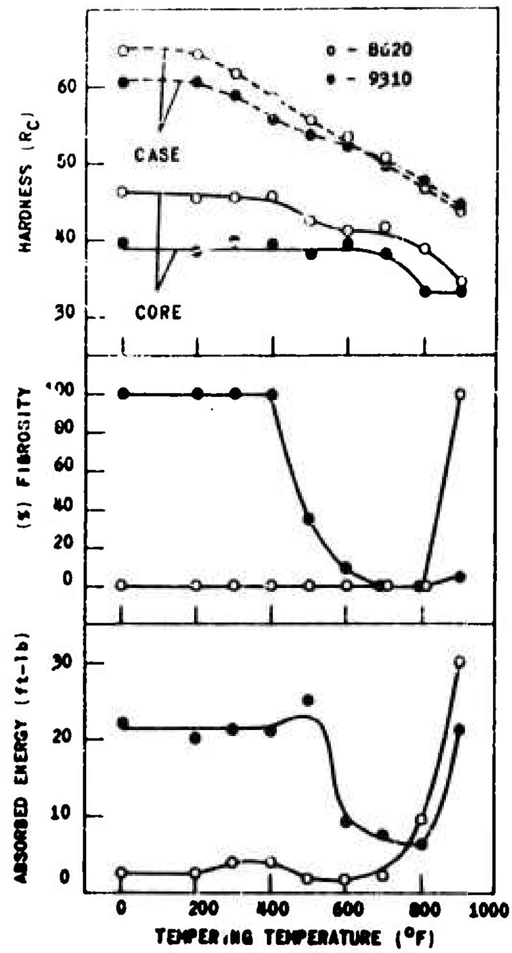


Figure 4. EFFECT OF TEMPERING TEMPERATURE ON HARDNESS AND V-NOTCH CHARPY IMPACT PROPERTIES AT -40 F - CARBURIZED SAE 9310 AND 8620 STEELS

in both materials over that obtained in the uncarburized condition. This comparison can be noted for the 9310 steel when tempered in the "blue brittle" temperature range (500 to 800 F) and for the 8620 steel at all tempering temperatures less than 900 F. Of major significance is the fact that the 9310 steel exhibited 100 percent fibrous fractures and absorbed considerable energy when tested in the carburized condition using the production tempering cycle. The 8620 steel, on the other hand, absorbed very little energy and exhibited crystalline fractures after a similar heat treatment. The 9310 steel possessed a martensitic microstructure and a core hardness of 38 to 40 Rockwell C using an oil quench and a tempering temperature under 500 F. The 8620 steel, on the other hand, which was water quenched in order to obtain a martensitic microstructure, possessed a core hardness of 45 to 47 Rockwell C.

Carburized Charpy impact specimens of both steels were tested as a function of test temperature to determine the transition temperature.

Both steels were processed to essentially the same core hardness level (40 Rockwell C) and the same case depth (0.015 inch). However, in order to employ a constant tempering temperature of 400 F, yet obtain the same core hardness, it was necessary to quench the 8620 steel in oil resulting in a microstructure which was 80 percent high temperature bainite as compared to the 100 percent martensitic structure in the 9310 steel. The impact transition curves of both energy and fracture appearance are shown in Figure 5. It is apparent that the 9310 steel maintains high toughness to a much lower test temperature than the 8620 steel. The transition temperature can be defined in a number of ways. It is defined here as the temperature at which a 50 percent fibrous fracture occurs. Under this criterion, the transition temperature is -100 C (-148 F) and +10 C (+50 F) for the 9310 and 8620 steels respectively. This large difference in transition temperature accounts for the marked difference in the impact properties obtained in the tests conducted at -40 C (-40 F). (See Figures 3 and 4.)

To investigate the conditions of the notch on the impact properties, some specimens were notched after carburizing and others by fatigue cracking the carburized layer in the notch prior to testing. Precracking was accomplished by vibration fatiguing specimens as simple beams under

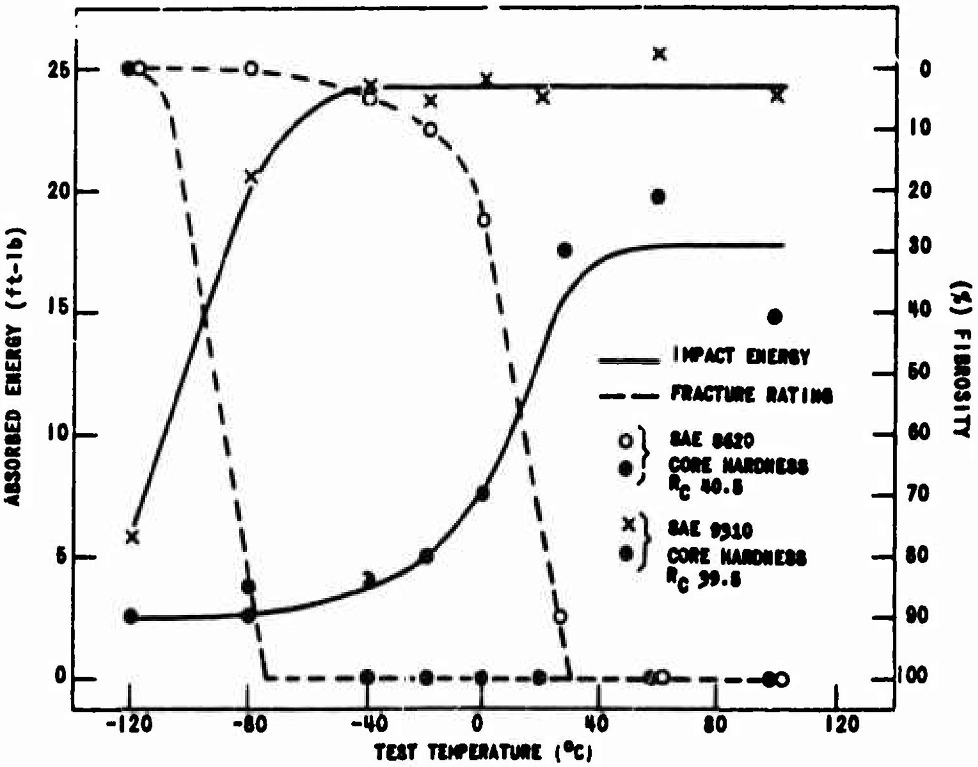


Figure 5. IMPACT ENERGY AND FRACTURE VERSUS TEST TEMPERATURE - SAE 9310 AND 8620 STEELS

controlled conditions to produce shallow cracks through the case at each specimen. The condition of the notch in the impact test is of interest in predicting the effect of notch severity on the service performance of rifle bolts which are frequently ground in the fillet area or which, during service, develop fatigue cracks in this area. These tests are also useful in assessing the effect of carburizing on the notch initiation energy in the Charpy impact test. The results (presented in Table V) revealed that there is very little difference between the energy absorbed by the carburized and the carburized-and-precracked specimens. This observation was made on material in both the tough (9310 steel) and brittle (8620 steel) conditions. However, notching the specimens after carburizing resulted in a significant increase in energy absorbed in both the tough and brittle conditions. It can be concluded that the carburized case under a notch absorbs little or no energy during impact loading to fracture.

TABLE V

EFFECT OF NOTCH CONDITION ON IMPACT PROPERTIES TESTED AT 0 C (+14 F)

Test Specimen	9310 Steel				8620 Steel			
	Heat* Treatment	Rockwell C Hardness		Impact Energy (ft-lb)	Heat* Treatment	Rockwell C Hardness		Impact Energy (ft-lb)
		Case	Core			Case	Core	
Carburized	A	56.0	39.5	24.7	C	59.5	47.0	4.0
					B	57.0	40.5	7.5
Carburized and Precracked	A	56.0	39.5	23.6 29.8	C	59.5	47.0	4.0 3.7
					B	57.0	40.5	6.2 10.3
Notched after Carburizing	A	56.0	39.5	32.9 36.1	C	59.5	47.0	9.2 8.6
					B	57.0	40.5	15.8 16.5

*Heat Treatments described in Table II.

Since Ordnance equipment (including the M14 rifle) is expected to operate satisfactorily down to -65 F, it is important to employ materials which have sufficient toughness so that they will not exhibit catastrophic failure (brittle fracture) at subzero temperatures. For carburized rifle bolts and receivers, the 9310 steel can be heat treated in production to a tough condition. The 8620 steel, on the other hand, is either quenched to excessively high hardness in order to obtain a martensitic structure or slack quenched to a lower hardness at which a high percentage of upper

bainite is obtained. In both instances, the core of the 8620 steel possesses low toughness and is susceptible to brittle fracture, particularly at low temperatures and/or in the presence of a high stress concentration.

The studies conducted to date indicate that the V-notch Charpy impact test is effective in assessing the toughness of carburized and heat-treated parts having approximately the same cross-sectional area. Consequently, this test is considered to be appropriate as a specification requirement for bolts and receivers of the M14 rifle in order to insure adequate toughness.

GENERAL CONSIDERATIONS

This limited study was conducted to assess the toughness of SAE 9310 steel as compared to SAE 8620 steel for application in carburized bolts and receivers used in the M14 rifle. The results show that 9310 steel, which has a high hardenability and low carbon content, can readily be carburized and heat treated to provide parts having a martensitic core microstructure with high toughness. Parts having large variations in thickness will possess a uniform core microstructure of tempered martensite and hardness of 38 to 42 Rockwell C, even with the fairly wide variations in quenching practice which are encountered in manufacturing plants. The use of high toughness steel such as 9310 in severely stressed carburized parts will provide very good reliability in service and reduce to a minimum any risk of premature catastrophic failure under service conditions of low temperature and/or high strain rates.

The high alloy content of 9310 steel results in a high percentage of retained austenite in the carburized case, a condition which results in low surface hardness. Since low surface hardness may lower the fatigue and wear resistance, it may be desirable to use a subzero conditioning treatment to transform the retained austenite. This subzero treatment is frequently employed on carburized components.

CONCLUSIONS

1. The core toughness of 9310 steel is markedly superior to that of 8620 steel in the carburized and heat-treated condition. The impact transition temperature of 9310 steel when carburized and heat treated to a core hardness of 40 Rockwell C is 100 C lower than that of 8620 steel possessing the same hardness.

2. Uniform core hardness and toughness are readily obtainable in carburized 9310 steel components even with wide variations in quenching practice and changes in section thickness because of the high hardenability and low carbon content of this steel.

3. The high alloy content of the 9310 steel results in a high percentage of retained austenite near the surface of the carburized parts when a one-cycle quench-and-temper heat treatment is employed. This condition can be alleviated by using a subzero conditioning treatment which transforms the retained austenite.

4. The V-notch Charpy impact test can and should be employed as a specification control test for small carburized parts when high toughness is required.

RECOMMENDATIONS

In order to establish more conclusively the overall applicability of 9310 steel for bolts and receivers used in M14 rifles, it is recommended that a limited number of components be manufactured for proof and service tests. During this pilot manufacture, the machinability of 9310 steel can be determined in relation to the particular parts and then the disadvantages, if any, can be assessed.

WATERTOWN ARSENAL
WATERTOWN 72, MASSACHUSETTS

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In the current investigation, the hardenability, microstructure and V-notch Charpy impact properties of SAE 9310 steel were evaluated. The results have been compared with those of 8620 steel, and recommendations are made regarding the use of the 9310 steel for carburized components for critical service applications.

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1. Small arms, rifle M14
2. Materials Evaluation
3. Carburized steel, 9310 and 8620

I. Riffin, Paul V.
II. Sliney, Joseph L.
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Watertown Arsenal Laboratories, Watertown 72, Mass.
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